Hope Bay Project, North Dam As-Built Report

Report Prepared for

Hope Bay Mining Ltd.

Report Prepared by

SRK Consulting (Canada) Inc.
1CH008.058
October 2012

Hope Bay Project,

North Dam As-Built Report

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List of Abbreviations

AFC - Arctic Foundations of Canada Inc.

EBA – EBA, A Tetra Tech Company

FCP - Frozen Core Plant

GCL - geosynthetic clay liner

GTC - ground temperature cables

HBML - Hope Bay Mining Limited

HDPE - High Density Polyethylene

IFC - Issued for Construction

JDS - JDS Energy & Mining Inc.

masl - meters above sea level

NMC – Newmont Mining Corporation

Nuna – Nuna Logistics Limited

NWB – Nunavut Water Board

OD - outer diameter

ppt – parts per thousand

PSD - particle size distribution

QA/QC - quality assurance/quality control

RFI - request for information

ROQ - run-of-quarry

SOP – standard operating procedure

SRK - SRK Consulting (Canada) Inc.

TCA - tailings containment area

TST – Thermosyphon status thermistor

1 Introduction

1.1 General

Hope Bay Mining Limited (HBML), a wholly owned subsidiary of Newmont Mining Corporation (NMC), retained SRK Consulting (Canada) Inc. (SRK) for the design and quality assurance services of a frozen core dam (North Dam) as part of the tailings management strategy for their Doris North Project. The Doris North Project is located approximately 400 km east of Kugluktuk and 160 km southwest of Cambridge Bay in the Kitikmeot region of Nunavut.

The North Dam was constructed during the winter months of 2011 and 2012. This as-built report contains as-built drawings and all associated quality control and quality assurance documentation pertaining to the dam.

1.2 Design Overview

The North Dam is one of two dams that will be constructed to form the Tail Lake tailings containment area (TCA). The North Dam is located over the Tail Lake outflow, between Tail Lake and Doris Lake, on saline overburden soils up to 20 m thick. During operation of the TCA, tailings will be deposited in the deepest portion of Tail Lake and only the water cover will be in contact with the dam, hence the North Dam is designed to be a water retaining structure utilizing a central frozen core. The design life of the dam is 25 years (SRK 2007).

Due to the depth of overburden soils in the dam alignment, the Key Trench was designed to terminate in the overburden soils. Thermosyphons at the base of the Key Trench provide passive cooling during the winter months to ensure that the foundation remains frozen. A geosynthetic clay liner (GCL) was installed along the upstream side of the frozen core to provide secondary water-retaining capability in case cracks develop in the core due to thermal expansion or creep deformation. The frozen core and GCL extend to elevation 35.3 meters above sea level (masl), which provides a 1.8 m freeboard above the full supply level of 33.5 masl. The shell of the dam was constructed of run-of-quarry (ROQ) rock and acts as a thermal cover over the frozen core. A transition layer was placed between the frozen core and the dam shell, as a filter layer, to provide protection against migration of core material under thawed conditions. The slopes of the dam shell are 6H:1V and 4H:1V for the upstream and downstream slopes respectively.

1.3 Participants

The parties involved with the construction of the North Dam are listed in Table 1-1.

Table 1-1 Parties Involved in the Construction of North Dam

Element	Company/Group
Client	Hope Bay Mining Limited
Owner's Representative	JDS Energy & Mining Inc.
Design	SRK Consulting (Canada) Inc.
Engineer of Record	SRK Consulting (Canada) Inc.
Site Construction QA/QC	SRK Consulting (Canada) Inc.
Laboratory Testing	EBA, a Tetra Tech Company
Site Surveyor	Nuna Logistics Limited
Construction Contractor	Nuna Logistics Limited
Liner Contractor	Nuna Logistics Limited
Thermosyphon Specialty Contractor	Arctic Foundations of Canada Inc.
Drilling Contractor	WestArc Drilling and Blasting Services Ltd.

1.4 Main Tasks and Timeline

SRK monitored the construction of the North Dam and the associated civil earthworks at Hope Bay between January 11 and November 14, 2011 and again between January 6 and May 7, 2012. The main tasks involved with construction of the dam included:

- Frozen Core Plant (FCP) pad construction
- Percolation testing
- Key Trench excavation
- Run-of-quarry (ROQ) material placement
- Transition material placement
- Ground temperature cable (GTC) installation
- Levelling course placement
- Core material placement
- Thermosyphon installation
- Lower GCL installation
- Seasonal suspension
- Upper GCL installation
- GCL cover material placement
- Instrumentation installation

A detailed breakdown and timeline of the North Dam construction activities are presented in Appendix M. A simplified timeline of the main construction tasks is presented below in Table 1-2.

Table 1-2 North Dam Construction Activities – Simplified Timeline

Activity	Period
Frozen Core Plant construction (includes building foundation, plant erection and commissioning)	Jan 10 to Mar 3, 2011
Percolation testing	Jan 22 to Feb 1, 2011
Key Trench excavation (includes excavation of Peat Zone and Soft Spot)	Feb 2 to Mar 24, 2011
ROQ placement	Jan 23 to Apr 13, 2011 Oct 22 to 26, 2011 Jan 7 to Apr 8, 2012
Transition material placement	Jan 23 to Apr 13, 2011 Jan 7 to Apr 8, 2012
GTC Installation	Feb 22 to Apr 29, 2011 Feb 8 to Mar 13, 2012
Levelling course placement	Feb 24 to Apr 24, 2011
Core material placement	Feb 27 to May 2, 2011 Jan 15 to Mar 27, 2012
Thermosyphon system installation (includes radiator and pile installation)	Mar 5 to Apr 19, 2011
Lower GCL installation	Apr 25 to Apr 29, 2011
Seasonal suspension (includes placement of thermal cover)	Apr 13 to Oct 22, 2011
Removal of thermal cover	Oct 22 to Oct 26, 2011 Jan 6 to Jan 27, 2012
Upper GCL installation	Mar 18 to Mar 31, 2012
GCL cover material placement	Mar 20 to Mar 31, 2012
Instrumentation installation (installation of deep settlement points, inclinometers, and surficial survey points)	Apr 14 to May 6, 2012
Data Acquisition System (Data logger) Installation	Aug 6 to Aug 9, 2012

1.5 Climatic Conditions

Figure 1 presents a summary of the average daily temperatures recorded on-site, and at the start and finish dates of the main construction tasks associated with the North Dam construction. On-site temperatures were obtained from the weather station located at Roberts Bay (Weather Underground 2012a and 2012b). On occasion the weather station on-site was not functioning; when this occurred, weather data from Cambridge Bay, Nunavut, was utilized to supplement the site data (Weather Underground 2012c).

During the North Dam construction period, the maximum recorded ambient air temperature was +24°C while the minimum was -41°C. Wind chill temperatures exceeded -60°C at times. During the 2011 core construction, the temperature varied between -3°C and -40°C and the average daily temperature was -22°C. During the 2012 core construction, temperatures varied between -8°C and -41°C with an average daily temperature of -27°C.

1.6 Photo Record

A photo log of the key construction activities is provided in Appendix G. Table 1-3 outlines the contents of the photo record.

Table 1-3 Contents of Photo Log

Photo Log Number:	Title
1	Overview of Dam Construction Activities
2	Overview of Dam Construction Activities
3	Percolation Testing
4	Drilling, Blasting, and Excavation of Key Trench
5	Final Cleaning of Key Trench and Cleaning Between Lifts
6	Levelling Course Placement
7	Thermosyphon Installation
8	Core Material Placement
9	GCL Placement
10	GCL Cover Material Placement
11	Transition Material Placement
12	Run-of-quarry Material Placement
13	Ground Temperature Cable Installation and Repair
14	Survey Monitoring Point Installation
15	Instrumentation Installation
16	Instrumentation Installation
17	Seasonal Suspension and Cover Placement
18	Frozen Core Plant
19	Material Testing

1.7 Report Layout

This report is broken down into seven sections, including this introduction. The second section of the report outlines the construction documents associated with the North Dam construction. Deviations from design which occurred during the construction of the dam are documented in Section 3; details of the actual construction are presented in Section 5. Section 4 describes the construction materials utilized during construction and Section 6 presents the results of quality control and quality assurance testing performed during dam construction. Section 7 outlines the long-term monitoring requirements associated with the dam. Figures and appendices can be found at the end of the report.

2 Construction Documentation

2.1 Construction Drawings

The complete set of construction drawings, including all revisions, is presented in Appendix A.2. Table 2-1 below lists details for the latest revision of each drawing which can be found in Appendix A.1.

Table 2-1 Issued for Construction Drawings

Drawing Number	Title	Latest Revision	Date of Issue
DN-ND-00	Engineering Drawings for North Dam	7	Apr 2, 2012
DN-ND-01	North Dam General Arrangement	1	Mar 31, 2011
DN-ND-02	North Dam Geological Section and Typical Cross Section	1	Feb 4, 2011
DN-ND-03	North Dam Key Trench Layout & Vertical Ground Temperature Cable Drill Holes	1	Dec 3, 2010
DN-ND-04	North Dam Thermosyphon Evaporator Pipe Layout	3	Feb 16, 2011
DN-ND-05	North Dam Geosynthetic Clay Liner Lower and Upper Layout	2	Feb 9, 2011
DN-ND-06	North Dam Core Layout	1	Feb 9, 2011
DN-ND-07	North Dam Transition Material Layout	1	Feb 4, 2011
DN-ND-08	North Dam Shell Access Road and Turnaround Layout	2	Apr 2, 2012
DN-ND-09	North Dam Vertical Ground Temperature Cables Layout	0	Dec 3, 2010
DN-ND-10	North Dam Horizontal Ground Temperature Cable Layout - Top of Liner	0	Dec 3, 2010
DN-ND-11	North Dam Horizontal Ground Temperature Cable Layout - Middle Core	0	Dec 3, 2010
DN-ND-12	North Dam Horizontal Ground Temperature Cable Layout - Upper Core	1	Feb 4, 2011
DN-ND-13	North Dam Ground Temperature Cables on Layout of Shell	0	Dec 3, 2010
DN-ND-14	North Dam Ground Temperature Cable Clusters at Chainage 0+40 and 0+60	1	Feb 4, 2011
DN-ND-15	North Dam Ground Temperature Cable Clusters at Chainage 0+85 and 1+30	1	Feb 4, 2011
DN-ND-16	North Dam Ground Temperature Cable Clusters at Chainage 1+75	3	Apr 2, 2012
DN-ND-17	North Dam Sections 0+10 to 0+40	0	Dec 3, 2010
DN-ND-18	North Dam Sections 0+45 to 0+55	0	Dec 3, 2010
DN-ND-19	North Dam Sections 0+60 to 0+70	0	Dec 3, 2010
DN-ND-20	North Dam Sections 0+75 to 0+85	0	Dec 3, 2010
DN-ND-21	North Dam Sections 0+90 to 1+00	0	Dec 3, 2010
DN-ND-22	North Dam Sections 1+05 to 1+15	0	Dec 3, 2010
DN-ND-23	North Dam Sections 1+20 to 1+30	0	Dec 3, 2010
DN-ND-24	North Dam Sections 1+35 to 1+55	0	Dec 3, 2010
DN-ND-25	North Dam Sections 1+60 to 1+85	0	Dec 3, 2010
DN-ND-26	North Dam Sections 1+90 to 2+10	0	Dec 3, 2010
DN-ND-27	North Dam Thermosyphon Details	2	Feb 9, 2011

Drawing Number	Title	Latest Revision	Date of Issue
DN-ND-28	North Dam Stake Out Coordinates for Instrument Clusters	0	Dec 3, 2010
DN-ND-29	North Dam Percolation Test Borehole Locations	1	Feb 4, 2011
DN-ND-30	North Dam Additional Instrumentation Layout	0	Feb 24,2012
DN-ND-31	North Dam Typical Additional Instrumentation Section and Details	1	Mar 19, 2012
DN-ND-32	North Dam Ground Temperature Cable Details	0	Mar 30, 2012

2.2 Technical Specifications

Four revisions of the Technical Specifications were issued during the construction of the North Dam. Revision G, the most recent revision, is included in Appendix C.

2.3 Construction Documentation

Construction documentation including memos, requests for information (RFIs), and site instructions are provided in appendices D, E and F, respectively. In many cases, these documents reflect the official means of communication between parties. Table 2-2 summarizes the RFIs received during the construction period by date of issue, while Appendix E contains the final RFI responses submitted by SRK. Issued for construction memos are summarized in Table 2-3, and site instructions, including SRK responses, are summarized in Table 2-4.

While on site, SRK also prepared daily reports summarizing site discussions and construction activities for all construction works in which they were involved, including the North Dam. A compilation of the SRK daily reports for 2011 can be found in the Doris North Project: 2011 Construction Summary (SRK 2011), and the 2012 daily reports can be found in the Doris North Project: 2012 Construction Summary (SRK 2012).

Table 2-2 Requests for Information

RFI Number	Date Issued	Topic
NL-RFI-015	Dec 15, 2010	North Dam access road
NL-RFI-014	Dec 16, 2010	Correction to estimated material quantities for GTC clusters
NL-RFI-020	Jan 1, 2011	Welding specifications
NL-RFI-022	Jan 26, 2011	Use of 1/16 inch minus fines material for GTC backfill
NL-RFI-025	Jan 27, 2011	Substituting higher grade A106-B pipe for the A53B pipe specified for thermosyphon installation
NL-RFI-026	Feb 4, 2011	Substituting bentonite chips for bentonite powder on GCL seams
NL-RFI-027	Feb 9, 2011	Request for 3D faces electronic file of North Dam design
JDS-RFI-001	Feb 18, 2011	Rate of bentonite application on GCL seams
JDS-RFI-002	Feb 18, 2011	Removal of turnaround
JDS-RFI-003	Feb 19, 2011	Removal of ice from the Tail Lake outflow, and the use of transition material to fill the area
JDS-RFI-004	Feb 20, 2011	Request that QA/QC test data be provided in a timely manner
JDS-RFI-005	Feb 23, 2011	Rerouting the ground temperature cable (GTC) leads for the Key Trench, lower and middle GTCs along the downstream side of the core
NL-RFI-039	Apr 2, 2011	Reduction of annulus for thermosyphon ad-freeze piles

RFI Number	Date Issued	Topic
NL-RFI-054	Jul 19, 2011	Survey monument base plates
JDS-RFI-080	Jan 22, 2012	GCL cover material
JDS-RFI-006	Feb 9, 2012	Core material placement in Fillet Expansion area

Table 2-3 Issued Construction Memos

Date Issued	Issued By	Subject
Jan 24, 2011	SRK	Doris North - North Dam Fillet Construction
Feb 15, 2011	SRK	Hope Bay Project - North Dam Additional Key Trench Excavation in Peat Zone
Feb 18, 2011	SRK	Hope Bay Project - North Dam Additional Excavation of Massive Surface Ice
Feb 18, 2011	JDS	North Dam - Key Trench Access Ramp
Feb 25, 2011	SRK	Hope Bay Project - Core Material PSD Testing and Stockpile Volumes
Apr 15, 2011	SRK	North Dam Close-out Plan for April/May 2011 - FINAL
Jul 8, 2011	SRK	Tail Lake Water Level
Mar 20, 2012	SRK	Doris North Project - North Dam Slope Indicator Instrumentation

Table 2-4 Site Instructions

Date Issued	Site Instruction Number	Issued By	Subject
Feb 8, 2011	NMCHOP-001-001	JDS	Vertical Ground Temperature Cable Installations
Feb 18, 2011	NMCHOP-JDS-002	JDS	Additional Vertical Ground Temperature Instrumentation
Feb 21, 2011	NMCHOP-JDS-002	SRK	SRK's Response to Site Instruction NMCHOP-JDS-002
Mar 16, 2011	NMCHOP-JDS-002 (1)	JDS	Additional Vertical Ground Temperature Instrumentation
Apr 24, 2011	NMCHOP-JDS-005	JDS	North Dam Interim Close-out Plan Spring 2011

2.4 Other Correspondence

Important email correspondence relating to the construction of the North Dam is compiled in Appendix N, and summarized chronologically in Table 2-5. Additional correspondence relating to the day-to-day activities of the North Dam construction can be found in the Construction Summary Reports (SRK 2011 and 2012).

Table 2-5 Summary of Important Correspondence

Date Sent	Subject
Jan 20, 2011	North Dam – Quality Assurance Program *SRK/EBA will conduct all materials testing; Nuna will not perform material testing.*
Feb 1, 2011	Drill and Blast *JDS informing SRK that they would like to perform a trial blast.*
Feb 1, 2011	FW: North Dam Key Trench Blast Design *Details of blast design.*
Feb 3, 2011	Perc Test Results and Key Trench Depth Determination *Details of percolation testing, with results of percolation testing attached.*
Feb 15, 2011	North Dam “Soft” Spot in Key Trench *No additional excavation of Soft Spot is required.*
Mar 5, 2011	Doris North – North Dam *Excessive water bleeding from core material.*
Mar 5, 2011	Hope Bay North Dam – Conference Call Notes. *Minutes from a conference call regarding the excessive water bleeding from the core material.*
Mar 7, 2011	Core Material Placement *SRK issued a formal statement regarding core placement.*
Mar 7, 2011	RE: Core Material Placement. *Core Placement specifications.*
Mar 10, 2011	Core Material – Acceptabe Belnd of Fines vs. Core Material *SRK issued a formal statement regarding core material blends.*
Mar 10, 2011	Removal of non-spec core material in key trench *SRK’s formal statement regarding the removal of non-spec core material.*
Mar 11, 2011	Hypersaline Area in North Dam Key Trench *SRK’s formal statement regarding the Soft Spot*.
Mar 28, 2011	One-Time Exception for meeting Freeze-Back Temperature. *SRK granted a one-time exception on the freeze-back requirement in the Peat Zone.*
Mar 29, 2011	North Dam – Excavation of Hypersaline Area. *SRK’s official record for over-excavating the zone within the Key Trench where hyper-saline soils were encountered.*
Mar 30, 2011	Fillet Zone Construction – Approved Variance *Reduction in specification in the Fillet Zone.*
Mar 31, 2011	RE: Location of Additional GTC *Additional GTC will not be installed.*
Apr 13, 2011	RE: placement of saturated core – 20110413 *Exception to freeze-back requirement.*
May 9, 2011	RE: Thermal Cover *Official record for reduction in thermal cover thickness.*
Aug 1, 2011	Re: Hope Bay – Tail Lake Discharge Pipe *Pipeline monitoring during pumping.*

Date Sent	Subject
Mar 3, 2012	Hope Bay – North Dam Transition Material on south end *Design change allowing placement of transition material in place of GCL cover material to bring the Key Trench up to grade at south end of the dam.*
Apr 3, 2012	RE: Survey monitoring point detail and discussion *Instruction from JDS that the survey monitoring points shall be fabricated and installed as-per design.*

Note: The non-italicized text is the subject from the original email, exactly as it was in the email subject line.

3 Deviations from Design Documents

3.1 General

In general, the North Dam was built to the lines, grades, and requirements outlined in the Issued for Construction Drawings and Technical Specifications (Appendix A and C). Deviations from the design documents are discussed in the following sections, and are also detailed in the as-built drawings (Appendix B).

3.2 Key Trench Excavation

Additional Key Trench excavation, beyond the lines and grades displayed in the design drawings, was required from station 0+90 to 1+05, and from 1+100 to 1+20, as detailed below.

Additional excavation from 0+90 to 1+05 was required to remove organic material noted at depth. All notable organic material in this area was removed from the base of the Key Trench.

Between station 1+00 and 1+20, a soft zone (Soft Spot) of less frozen (hyper-saline) overburden was encountered at design elevation for the width of the Key Trench. Six short boreholes were drilled to assess the extent of the hyper-saline zone. As salinity values higher than design were measured, the overburden on the downstream side of the dam, from station 1+00 to 1+20, was excavated to an elevation of 24.5 masl. This excavation of the saline material was completed to reduce the probability of the foundation experiencing increased rates of creep, and thus reducing the potential for increased differential movement occurring in the core. A large portion (but not all) of the hyper-saline overburden was removed. Salinity testing results for the area can be found in Appendix H.8. Additional details on the final extent of the Key Trench excavation are presented in the as-built drawings (Appendix B).

3.3 Core Material

Core material falling within the particle size distribution envelope, as outlined in the Technical Specifications (Appendix C), was found to excessively bleed water during placement. Therefore, core material that exceeded the upper particle size limit (i.e., contained more fines) was used for frozen core construction. Additional details on the particle size distribution of the core material are presented in Section 4.

3.4 Fillet Zone

The saturation and freeze-back requirements for frozen core material within the fillet zone (the wedge-shaped area of material on the upstream side below the liner and outside of the main core mass) were relaxed to increase constructability. The relaxed requirements for the fillet material are:

- Moisture content not less than optimum
- Compaction must be above 95% of the Standard Proctor density
- Freeze-back was not required between lift placement

The relaxed specifications for the fillet area did not apply to the first two lifts (0.5 m) above the GCL base level. This area had to meet the regular saturation, moisture content, freeze-back, and compaction requirements.

3.5 Lower GCL Extension

Core material which did not meet the saturation requirements was placed on March 3, 2011, and was subsequently covered with core material that met the specifications on March 6, 2011. In order to reduce unnecessary construction delays, only a portion of this material (a minimum of 3 m wide), was removed from the downstream side and replaced with material meeting the Technical Specifications (Appendix C). To ensure no short-circuiting seepage occurs in the future, the lower GCL was extended to the back of the Key Trench. The extents of the lower GCL extension can be seen in as-built drawing DN-ND-05 (Appendix B).

3.6 Thermosyphons

The specified pipe grade for the thermosyphons pipes was substituted with A106-B grade pipes. The A106-B grade is a higher grade of steel piping than that specified in the Technical Specifications (Appendix C).

Due to the availability of equipment on site, the annulus of the thermosyphon radiator piles was reduced to 25 mm. As a result of the reduced pile annulus, the embedment length of the piles was increased to 7 m. This change is documented in NL-RFI-039 (Appendix E).

3.7 Turn-Around and Access Road

The turnaround on the south-east end of the dam was not constructed. Where the turnaround was to be constructed, the ROQ material was daylighted into the tundra at dam crest elevation. Additionally, the 0.15 m of surfacing material, which was to be placed along the crest of the dam to serve as road surfacing, was not placed for the entire length of the access road. The purpose of these items was to improve access and turning for maintenance vehicles, and the removal of both does not change the design intent of the dam.

The access road connecting the dam to the Secondary Road was not built to design height. This in itself does not change the design intent, provided that the minimum 1 m fill thickness is met. However, based on the provided survey data, portions of the access road are less than 1 m; consequently the design intent of maintaining a minimum 1 m of thermal cover is not met.

Transition material was substituted for ROQ material to construct a portion of the access road. This substitution does not change the design intent of the dam.

3.8 Ground Temperature Cables

The annuli of the vertical ground temperature cables (GTC) were backfilled with dry, manufactured fines material rather than frozen core material or a slurry consisting of manufactured fines and water.

Leads from the vertical Key Trench, lower and middle horizontal GTCs were designed to be run out to the downstream side of the dam at each horizontal GTC elevation. However, during construction, these thermistor leads were run up the downstream edge of the dam core, and then run horizontally to the downstream side of the dam, at the upper horizontal GTC elevation. Compacted, unsaturated core material (or other suitable crush material) was placed around the cables as bedding material for protection from the ROQ material. Additional details on this design deviation are outlined in JDS-RFI-005 (Appendix E).

Rather than run the GTC leads through a pipe placed on the surface of the dam as shown in issued for construction (IFC) drawings DN-ND-12 to DN-ND-15 (Appendix A), GTC leads were bedded in trenches approximately 1 m deep and 1.2 m wide excavated into the dam shell. Crush material was placed above and below the cables as protection from the ROQ backfill. Caution tape was placed on the top of the crush material to indicate a danger if the area is excavated at some point in the future. Most of the buttresses at the toe of the dam around the conduit pipes were not constructed as they were no longer required. GTC's ND-VTS-060-DS and ND-VTS-085-DS were encased in pipe a portion of the way up the slope of the dam, and buttresses were constructed around these pipes at the toe of the dam.

3.9 GCL Cover Material

The placed GCL cover material met the original particle-size distribution requirements in the Technical Specifications (Appendix C), rather than the finer frozen core material utilized elsewhere. Freeze-back was not required between lifts, or before the placement of transition material.

3.10 Transition Material

From stations 0+25 to 0+45, the GCL cover material was placed in a 0.3 m lift over the GCL material, rather than to the original ground elevation on the upstream side. The remaining area below the original ground elevation was built up in compacted lifts with transition material.

3.11 Fillet Extension

Construction of the North Dam could not be completed in one season as intended; therefore, the liner had to be raised to allow for the suspension of dam construction until the 2012 winter season. The frozen core within the fillet area and the lower GCL of the dam were raised to an elevation of 29.8 masl. The fillet was extended at the 2.5H:1V slope up to an elevation of 29.8 masl. The GCL was laid on this slope. The fillet extension was constructed using the same variance as the fillet.

The upper slope of the frozen core material was constructed as per design with the exception of the material below an elevation of 29.8 masl, which was extended horizontally from the design slope to the extended fillet area. The upper GCL was extended horizontally from the lower GCL to the design slope, and then the GCL followed the design lines up the slope. Additional details on the seasonal suspension and selected fillet extension option are presented in Appendix D.

4 Construction Materials

A variety of materials were used in constructing the North Dam. The rock and granular materials were produced on-site by quarrying and crushing, while other materials were sourced from manufacturers off-site. Table 4-1 presents a summary of the materials used, as well as the location and the source of the material.

Table 4-1 Summary of Materials used at North Dam

Material	Location (Use)	Source
Run-of-quarry (ROQ)	Dam shell (external dam shell)	Quarry #2
Transition - 150 mm (6 inch) minus crush	Dam transition (filter between the frozen core and the dam shell)	Quarry #2, on-site crusher
Core - 20 mm (3/4 inch) minus crush	Frozen core (blended with manufactured fines to produce the final core blend)	Quarry #2, on-site crusher
16 mm (5/8 inch) minus clear crush	Temporary cover for seasonal suspension (indicator and GCL protection layer)	Quarry #2, on-site crusher
Core - 5 mm (3/16 inch) minus crush	Frozen core (frozen core construction material)	Quarry #2, on-site crusher
Core – manufactured fines	Frozen core (blended with 20 mm minus crush to produce the final core blend)	Quarry #2, on-site crusher
Water	Frozen core (moisture conditioning of core aggregate in FCP)	Doris Lake
Geosynthetic Clay Liner (GCL)	Frozen core (secondary water retention system)	Nilex Inc.
High density polyethylene (HDPE)	Frozen core (temporary protection for GCL)	GSE Environmental
Bentonite powder	Frozen core (GCL seams and water stops for ground temperature cables)	Off-site vendor
Steel pipe	Dam shell and transition (casings for settlement monuments, slope indicators, and ground temperature cables; thermosyphon evaporator pipes; adfreeze piles for thermosyphon radiators superstructure)	Various off-site vendors

4.1 Run-Of-Quarry Materials

All run-of-quarry (ROQ) material used as dam shell material is non-acid generating basalt, quarried on-site from Quarry #2 by drilling and blasting methods. The overburden was stripped before blasting, while oversize was sorted during the loading of the haul trucks. Select ROQ was used as crusher feed. Maximum size and gradation requirements were as detailed in the Technical Specifications (Appendix C). In general, the ROQ was noted to have adequate fines and few oversize pieces.

4.2 Transition Materials

This material was produced by the on-site crusher using the primary jaw circuit only. The 150 mm crush was used as transition material between the frozen core and the dam shell, and satisfies the filter criteria for frozen core migration. Maximum size and gradation requirements were as described in the Technical Specifications (Appendix C).

In general, the transitional material was noted to be clean with no gravel and sand and with very little fines. The crushed material was stockpiled near the crusher and hauled to a smaller stockpile at the dam as needed.

4.3 Core Materials

4.3.1 20 mm Minus Crush Material

The 20 mm minus crush was produced to meet the Technical Specifications (Appendix C) for core material gradation, but field trials revealed that the material did not hold water as expected; material placed during the field trials bled water excessively. To remedy this issue, the fines content was increased by blending the 20 mm minus core material with manufactured fines. A variety of blending ratios were tested with a 2:3 (20 mm minus core material: manufactured fines) ratio found as optimum and adopted for construction.

When construction resumed in 2012, some of the 2:3 blend core material produced in 2011 (stockpiled near the Frozen Core Plant) had to be re-crushed due to the presence of excessive amounts of large (boulder size) frozen clumps. This re-crushed aggregate presented some operational challenges in the mixing process, related to achieving the target moisture content at placement, because of the variable “natural” moisture content within the stockpiled material.

Extensive particle size distribution (PSD) testing was performed on this blend, to ensure consistency and adherence to the specifications. The PSD curves are summarised in Figure 2.

4.3.2 5 mm (3/16 inch) Minus Crush Material

This material was produced in 2012 by re-crushing the 20 mm minus crush material. Once the 2:3 core material blend produced and stockpiled in 2011 was used up, this finer material was used for the balance of the 2012 construction season, although it did not meet the Technical Specifications (Appendix C) with respect to the coarse fraction. Extensive gradation testing was done for this material. The test certificates are included in Appendix H.1 and the PSD curves are summarised in Figure 2.

4.3.3 Manufactured Fines Material

The manufactured fines were produced by the on-site crusher as a means of increasing the fines content of the frozen core material by blending it with the 20 mm minus crush material. The test certificates are included in Appendix H.1.

4.4 GCL Cover Material

The GCL cover material was produced during the 2012 construction season by blending the 5 mm minus core material with the 20 mm minus core material. This was done to reduce the volume of required 5 mm minus material. The particle size distribution of this material met the guidelines for core material in the Technical Specifications (Appendix C).

4.5 16 mm (5/8 inch) Minus Clear Material

The 16 mm minus clear material was the by-product of the manufactured fines production at the crusher. It was a very clean material, with very little to no fines. This material was used wherever possible throughout the site as filler. At the North Dam, a temporary 0.3 m lift of this material was laid out on top of the HDPE covering the GCL, as well as over the entire extent of the Frozen Core. This was done in April 2011 in preparation for suspending the core construction activities due to rising ambient temperatures.

4.6 Water

Water for moisture conditioning of the frozen core aggregate was sourced directly from Doris Lake and hauled to the Frozen Core Plant using tanker trucks. In the plant, water was stored in a 36 m^3 production tank, where it was kept from freezing by built-in electrical heating coils. Testing of the water for construction purposes was not carried out; however Doris Lake is the source of all potable and non-potable water from the project and as such is routinely tested. No elements in the water would affect the construction.

4.7 Geosynthetic Clay Liner (GCL)

The GCL was manufactured by Cetco according to specifications by Nilex, with a maximum hydraulic conductivity of $5x10^{-9}$ cm/s. Detailed technical specifications are presented in Appendix C.

The majority of the GCL liner (27 rolls) was brought to site with the 2010 sealift and stored on-site over the summer in open-air conditions. The plastic wrapping of some of the rolls was torn. Due to improper handling, signs of deterioration were noted in the form of hydration and tears on some rolls. In the early winter of 2010 the rolls were relocated into warm storage to thaw.

The deteriorated portions of the liner rolls were removed at time of placement. To replace the deteriorated portions of the liner, a new batch of 16 rolls of GCL was acquired. During the 2012 season, the rolls were stored in Seacan containers and were warmed up immediately before deployment to improve manageability.

4.8 High Density Polyethylene (HDPE) Liner

HDPE liner was used during the seasonal suspension in the spring of 2011 to protect the exposed portions of the GCL and keep it clean of dirt and snow. A full width of the roll was laid out over the GCL and was subsequently removed when construction resumed in 2012. The HDPE liner existing on site (purchased for other uses) was 60 mil (1.53 mm) thick, presented in 5 m wide rolls. The liner was manufactured by GSE Lining Technology Inc. and acquired from A&A Technical in Yellowknife.

4.9 Bentonite Powder

Bentonite powder was used to seal the joints between the overlapping panels of GCL, as well as sealing the patches where repairs were required. The bentonite used was bagged Baroid Granular Bentonite manufactured by Halliburton.

4.10 Steel Pipe

Various diameters and grades of steel pipe were used from various vendors to construct the following components:

- Thermosyphon evaporators – A106B stainless steel, 102 mm (4 inch) Schedule 40
- Adfreeze piles for thermosyphon radiators – 152 mm (6 inch) Schedule 40
- Deep settlement monument casings – 102 mm (4 inch) Schedule 40
- Inclinometer casings – 102 mm (4 inch) Schedule 40
- Data transfer cable conduits – 102 mm (4 inch) Schedule 40
- Data logger support posts – 152 mm (6 inch) Schedule 40

In addition, steel plates and steel rods were used to manufacture the settlement monuments, as detailed on IFC drawing DN-ND-16 (Appendix A). C-channel (C310x37) steel members were also used for the thermosyphon radiators support structure, as detailed on IFC drawing DN-ND-27. All steel with the exception of the thermosyphon steel was mild steel.

4.11 Material Quantities

The as-built material quantities used for the North Dam construction are summarized in Table 4-2. In-place quantities are derived from survey data supplied by Nuna. The in-place ROQ quantity includes the crush material surrounding the ground temperature cable leads.

Table 4-2 In-Place and Design Material Quantities

Material	Quantity	
	As-Built	Design
Key Trench Excavation	9,800 m^3	7,700 m^3
Levelling Course (Core Material)	5,070 m^3	1,066 m^3
Core Material (excluding levelling course)	16,020 m^3	14,720 m^3
Lower GCL*	3,433 m^2	2,441 m^2
Upper GCL*	3,331 m^2	2,597 m^2
Transition Material	6,700 m^3	6,600 m^3
ROQ Material (Dam and Access Road)	41,300 m^3	36,037 m^3
Surfacing Material (Dam and Access Road)	Survey Information Not Available	474 m^3
ROQ Material (Turnaround)	-	1,491 m^3
Surfacing Material (Turnaround)	-	94 m^3

Note: *GCL quantities do not account for patches, overlaps or wastage.

5 Dam Construction

5.1 Equipment

5.1.1 Mobile Equipment

Conventional earth moving equipment was used in construction of the North Dam as listed in Table 5-1.

A variety of other mobile equipment was also used to support the earthworks activities, including an air compressor, light plants, air heaters, and a flat-bed truck.

Table 5-1 Summary of Mobile Equipment used for Dam Construction

Equipment Type	Manufacturer	Model	Tool Attachments
Bulldozer	Caterpillar	D6	n/a
	Caterpillar	D8	Ripper tooth
Backhoe Excavator	Caterpillar	385	n/a
	Caterpillar	345	Air Drill
	Caterpillar	330	Ripper tooth
	Caterpillar	325	n/a
	Caterpillar	308	n/a
Front End Loader	Caterpillar	IT38/930	Integrated tool carrier
	Caterpillar	980	n/a
	Caterpillar	988	Lifting forks
Off-Road Truck	Caterpillar	730	n/a
	Caterpillar	725	n/a
Vibratory Drum Compactor	Caterpillar	CS-563	n/a
Hand Compactor	Bomag	BPR 30/38 D-3	n/a
	Mikasa	MVC-90L	n/a
Skid Steer Loader	Caterpillar	252B	Mechanical broom
Air Drill	Sandvik	DX-800	n/a
Power tools (electrical or compressed air)	Hilti, Atlas Copco, Ingersoll Rand, Wacker, Magnum, Hermann Nelson, Frost Fighter, etc.	n/a	Electrical jack hammer; air compressor with lance, light plants, air heaters, etc.

5.1.2 Crusher

The core and transition material was crushed using a Clemro crusher. The crushing circuit consisted of a primary jaw crusher, a classification screen, and a secondary cone crusher. A CAT 980 loader was used to feed the crusher with select run-of-quarry (ROQ), sourced exclusively from Quarry #2. In 2010 the crusher was located on the crusher pad north of Quarry #2, and subsequently moved to a location within Quarry #2. The crushed transition material and part of the 20 mm minus core material produced in 2010 was stockpiled on the north end of the crusher pad, while the entire volume of core material produced in 2011 was stockpiled in individual piles on the floor of Quarry #2. From the stockpiles, the core and transition materials were loaded into trucks and hauled to the dam or onto stockpiles on the Frozen Core Plant pad.

5.1.3 Core Mixing Plant

The frozen core aggregate was water conditioned using an Aesco-Madsen asphalt plant rated at a throughput of 130 tons per hour of dry aggregate. The dry aggregate was fed into the plant by a loader, through a hopper fitted with a grizzly screen, which was located outside of the plant building. The plant heated and dried the aggregate in the first section of the rotating drum, and subsequently mixed it with the specified ratio of water. The amount of water was controlled by adjusting the speed of a positive displacement pump. The water-conditioned aggregate was then loaded into haul trucks through an overhead conveyor belt and hopper bin, and hauled to the dam.

5.2 Survey

Survey control and reporting was performed by Nuna Logistics Limited (Nuna). Surveying was performed with Trimble GPS equipment using the UTM zone 13 coordinate system and NAD83 datum. Over the final core surface, a total station was used to compliment and increase survey accuracy. All survey data was processed on site by Nuna surveyors. The survey data was used to check grades, minimum thicknesses, and extents for field decisions, as well as to prepare the as-built drawings.

5.3 Foundation Preparation

5.3.1 Percolation Testing

Prior to the Key Trench excavation, a percolation testing program was undertaken to verify the foundation conditions assumed in the Key Trench design. This program was completed between January 28 and February 1, 2011. Twenty-three boreholes were drilled with a Sandvik DX-800 Air Track drill, to depths between 6.6 m and 9.3 m. Around the inflection point of the Key Trench, a tighter spacing of drill holes was used to better delineate the organic rich area identified in past investigations near the location of Tail Lake Outflow. The location of the completed percolation test holes is presented in as-built drawing DN-ND-29 (Appendix B).

After drilling, the percolation holes were filled with water. If the holes were not immediately tested, then they were plugged/ capped with insulation and marked with delineator cones. Typically, measurements of the depth to the static water level were taken frequently for the first four to five hours, and a final reading was taken at the end of the day or on a subsequent day.

Upon completion of the analysis and review of the percolation field and laboratory testing data, the depth to competent ice saturated soil was inferred. From the percolation testing results, it was concluded that no change was justified to the IFC Key Trench design grades. Notwithstanding, it was determined that additional excavation of the central section of the Key Trench was required to remove the organic material at depth (i.e., the Peat Zone identified on the original IFC drawings, approximately between chainage 0+90 and 1+05). Section 5.3.3 presents additional details on the aforementioned excavation. Results of the percolation testing are summarized in Table 5-2 below and presented in detail in Appendix J.

Table 5-2 Summary of Field Percolation Testing

Location	Station	Percolation Hole ID	Depth of Percolation Hole (m)	Depth to Static Water Level (m)
Downstream	0+ 30	P1	7.55	0.80
	0+ 52	P2	7.48	0.81
	0+ 75	P3	8.60	1.10
	0+ 90	P4	7.70	0.10
	0+ 97	P5	9.45	0.05
	1+ 03	P6	8.55	0.36
	1+ 20	P7	6.60	0.45
	1+ 55	P8	7.50	0.46
	1+ 59	P9	9.25	0.36
	1+ 91	P10	7.52	0.05
Upstream	0+ 50	P12	7.40	0.78
	0+ 74	P13	8.30	0.26
	0+ 91	P14	7.80	0.90
	0+ 99	P15	7.25	0.34
	1+ 03	P16	7.30	0.29
	1+ 19	P17	8.30	0.82
	1+ 49	P18	7.85	0.28
	1+ 61	P19	7.80	0.15
	1+ 77	P24	7.25	0.14
	1+ 91	P20	7.52	0.00
Middle/Inflection Area	0+ 90	P23	7.30	0.29
	0+ 96	P22	8.85	1.10
	1+ 01	P21	8.30	0.23

5.3.2 Drilling, Blasting, and Excavation of Key Trench

The Key Trench was excavated in 2011 from February 2 to February 16 using drill and blast methods. The blast holes were drilled to a depth of 2 m, with an over-drill allowance of 0.5 m, resulting in an average depth of the excavation of 2.5 m. The original drill pattern was laid out on a triangular pattern with 2.25 m between the holes, but the as-built patterns show a reduction in actual hole spacing to between 1.7 m and 1.9 m. The target powder factor was 0.70 kg/m^3.

A Peat Zone extending throughout the entire width of the Key Trench at station 0+85 was anticipated based on the subsurface investigations, and was initially excavated to the design extents. However, subsequent inspection of the area triggered further excavations, resulting in an over-excavation covering about 80 m^2 at the foot of the upstream wall to a maximum depth of 3 m below the base elevation of the Key Trench. As-built drawing DN-ND-03 (Appendix B) shows the surface of the final Key Trench excavation compared to the design model.

Immediately northeast of the Peat Zone, a hyper-saline zone was encountered with salinity as high as 90 ppm. Salinity test reports are attached in Appendix H.8. The high unfrozen water content and associated uncertainty with assessing adequate creep parameters to these materials led to the decision to excavate as much of the hyper-saline soils (Soft Spot) as practical.

The Soft Spot covered an area of approximately 20 m long by 18 m wide, touching the downstream wall of the Key Trench from station 1+00 to Station 1+20. An approximate volume of 300 m^3 of hyper-saline material was excavated, together with one lift (approximately 87 m^3) of frozen core material previously placed over this area. The excavation was subsequently backfilled with frozen core material, as per the Technical Specifications (Appendix C).

A large zone of massive surface ice about 40 cm thick and of variable width was found on the upstream side of the Key Trench near Station 0+85. The source of the ice was likely water ponding in the creek bed and then freezing in place. The bulk of the ice was removed using an excavator for a length of about 8 m, from the crest of the Key Trench excavation to the already placed ROQ on the upstream side. The exact extent of the ice was difficult to determine.

All overburden soils excavated and removed from the Key Trench were hauled to the overburden dump near Doris Camp.

5.3.3 Cleaning of Key Trench

Final cleaning of the exposed overburden foundation was performed with an air compressor and skid steer with broom attachment, as well as manually with brooms, ice picks, and shovels. The Key Trench was cleaned of all loose material, snow, and ice. Cleaned surfaces were then inspected by a field engineer before placement of frozen core material proceeded in any area.

5.3.4 Levelling Course Placement

A levelling course of core material was required to be placed in the Key Trench excavation to bring the elevation of the Key Trench to the base of the thermosyphon evaporator pipes. Once the pipes were installed, additional core material was placed over them before lower GCL placement. The levelling course material was moisture-conditioned in the Frozen Core Plant to a saturated condition prior to placement. Levelling course placement commenced in the Key Trench on February 24, 2011 and was completed on March 27, 2011.

The levelling course was up to 4 m thick and was typically placed in 0.2 to 0.4 m lifts. For the first lifts in the deepest portion of the Key Trench excavation, around the previously organic rich Peat Zone, saturated bedding material was compacted with a concrete vibrator until larger equipment was able to work in the area. In the area of the hyper-saline material excavation, immediately northeast of the Peat Zone, an additional volume of levelling course (beyond what was outlined in the IFC drawings) was placed to bring the Key Trench up to the design lines and grades.

Material was typically transported by CAT 730, CAT 725, and CAT 773 trucks from the Quarry #2 crusher, where it was produced, and stockpiled at the Frozen Core Plant pad. From the Frozen Core Plant, CAT 730 trucks would typically transport the saturated material to the Key Trench. CAT 330 and CAT 325 excavators, as well as the CAT D6 bulldozer were used for placing and spreading the bedding layer. A CAT CS-563 smooth 10 tonne drum vibratory compactor was used to pack each lift of the levelling course. Along hard to access areas, immediately adjacent to the upstream and downstream Key Trench, plate tampers were used. For very hard to access areas at the base of the Key Trench, the concrete vibrator was used. Compaction efforts ceased before the levelling course started to freeze and after saturation and compaction requirements were met. No construction equipment was permitted to travel on the levelling course layers after initial placement, until the temperature of the lift had reached -2°C (freeze-back). Between lift placements, all areas where notable ice and snow had formed were scraped and cleaned, as well as areas that were disturbed by equipment.

5.4 Thermosyphon Installation

Thermosyphon construction took place from March 5 to April 19, 2011. One series of six evaporator pipes was installed on the north end of the Key Trench, and another set of six were installed on the south end. These thermosyphon sets were placed along the graded levelling course from the radiators near the north and south downstream toe, then towards the lowest point of the Key Trench at chainage 0+85. The levelling course was sloped towards the inflection point at grades greater than 5% (1:20).

Thermosyphons were procured and installed by Arctic Foundations of Canada Inc. (AFC). Nuna provided equipment and labour support during the installation of the thermosyphon system, and WestArc Drilling and Blasting installed the adfreeze piles to support the radiators. The thermosyphons were installed as follows:

- Main segments of pipes were welded together in a shack constructed on the upstream dam shell.
- Lengths of welded pipe were dragged and lifted into place with an excavator and labour crew.
- Pipes were trimmed, and then the joints/elbows around stations 0+35 and 1+85 were welded to turn the pipes towards the radiators.
- Adfreeze piles to support the thermosyphon radiators were installed.
- The radiator support systems (c-channel steel connected to the adfreeze piles) were constructed.
- The thermosyphon radiators were lifted into place with a crane connected to the radiator support system and then welded to evaporator pipes.
- Thermosyphons were moved into final arrangement with a labour crew guided by survey.
- Completed thermosyphons were vacuumed, charged with carbon dioxide, and checked for leaks.
- Thermosyphons extending out of the Key Trench were covered with dry core material and the areas within the core of the dam were covered with the next lift of saturated core material.
- **Note:** A minimum of 0.4 m to 0.6 m of core material was required before smaller equipment was allowed to travel over the thermosyphon pipes.

The location of the thermosyphon evaporator pipes, piles, and radiators are presented in as-built drawings DN-ND-04 and DN-ND-27 (Appendix B).

5.5 Core Construction

As outlined in Section 4.3, 20 mm material blended with manufactured fines or 5 mm minus crush was used to construct the North Dam frozen core. These core materials were moisture-conditioned in the Frozen Core Plant to have moistures typically between the ranges of 9 to 13%. The mixing drum temperature in the Frozen Core Plant was varied based on the materials being used, moisture content, and outside wind and ambient air conditions. The aim was to keep temperatures warm enough to allow for better bonding between lifts and for placement and compaction activities to result, before interstitial ice developed. There was a trade-off between keeping the core material warm enough for placement and keeping temperatures as low as possible to reduce the time required for freeze-back during each placement. The temperature of the core material was typically around 28 to 43°C (approximately 33°C on average). Frozen core construction occurred between February 27 and May 2, 2011, and between January 15 and March 27, 2012.

Moisture-conditioned core material was hauled from the Frozen Core Plant to the dam by CAT 730 or CAT 725 haul trucks for placement. Access was originally achieved through the use of the thermosyphon trenches. Later, ramps with ROQ and/or transition material were used to provide access from the north and south ends around chainage 0+75. As the core superstructure was built up, access across the entire downstream was realized by bringing up the ROQ and transition material in horizontal lifts with the core.

Material was dumped in the Key Trench and typically spread into 250 to 300 mm lifts with an excavator (CAT 325, 330, or 345). For a few lifts in the 2011 construction season, the CAT D6 bulldozer was used to spread the core material for the first couple of lifts above the thermosyphons. A CAT CS-563 smooth 10 tonne drum vibratory compactor used static and vibratory passes to compact each lift. Typically, 6 to 10 passes (there and back is considered two passes) were made before an area was left to freeze.

To monitor freeze-back after placement and compaction activities were completed, a minimum of one, single bead thermistor was installed approximately three-quarters of the way into a representative area of the lift. Once the lift was frozen to -2°C an excavator would remove loose material, larger snow drifts and ice before the surface was cleaned.

As the core superstructure was constructed above the original ground elevation, the downstream side of the core was slightly overbuilt to ensure that IFC design lines were met or exceeded. This also allowed for transition material to be placed against the downstream side as core placement proceeded. The final 2.5H:1V upstream slope of the core superstructure was shaped as each lift progressed. Typically, the excavator would overbuild the upstream slope, the vibratory compactor would compact the area, the excavator would trim back most of the overbuild, then the labour crew would finish the surface with rakes. Before the upper GCL liner was deployed, the upstream slope was scraped down with an excavator and blown free of any debris with the air compressor.

As-built layouts for the completed core are outlined in drawings DN-ND-06 and in the sections on DN-ND-16 to DN-ND-26 (Appendix B). Photos of core material placement are included in the photo record in Appendix G.

5.6 Seasonal Suspension

Construction of the North Dam was not completed by the onset of warmer temperatures in spring 2011, and therefore the construction was suspended until fall 2011/winter 2012. Prior to seasonal suspension, the fillet of the dam was raised to 29.8 masl, as discussed in Section 3.11, and a minimum of two lifts of core material were placed over the lower GCL. As-built figure DN-ND-02 and DN-ND-19 to DN-ND-23 show the fillet raise in section and as-built figure DN-ND-06 shows the fillet raise in plan (Appendix B).

A thermal cover consisting of 0.5 m of 16 mm (5/8 inch) clear material and 2.0 m of ROQ material was placed over the frozen core to prevent thawing of the core. The 16 mm clear material was used as an indicator material to assist with the cover removal. Some areas of the frozen core near the inflection point had not achieved freeze-back prior to thermal cover placement, but the thermal cover was placed regardless to prevent additional thawing. No vehicle travel was allowed directly on the unfrozen material during cover placement.

Several single bead thermistors were embedded within the top two layers of the frozen core to monitor the effects of the thermal cover. During the summer months of 2011, the top two layers of core material warmed up, but none of the beads recorded temperatures above freezing (0°C). Figure 30 shows the temperature measurements within the top two layers of core.

Removal of the thermal cover occurred from October 22 to 26, 2011, and was then halted until January 2012. Final cover removal occurred in January 2012. Excavator scraping of the frozen core surface was required to remove 16 mm (5/8 inch) clear material, which had become embedded in the top of the frozen core. No frozen core material was removed. The CAT D8 bulldozer and CAT 330 excavator were used to remove the thermal cover. The frozen core surface was then inspected by the field engineer and approved prior to 2012 frozen core material placement.

5.7 GCL Placement

GCL panels were placed perpendicular to the dam axis, with a 0.5 m overlap between panels. A 100 tonne crane or excavator was used to lift the rolls of GCL, while labourers ensured the panels were properly aligned. Labourers placed a line of bentonite in the seams between panels at a minimum application rate of 0.4 kg/m. Patches were placed over holes, areas of visible damage, or hydration. A few panels of both the upper and lower GCL had horizontal seams located along the slope; these seams had an overlap of 1 m and were placed with the approval of the Construction Manager, against SRK's recommendation. Details on the GCL panel layout are presented on as-built drawing DN-ND-05 (Appendix B).

Placement and subsequent removal of the thermal cover, required for the seasonal suspension, caused significant damage to a portion of the lower GCL in the joint area between the upper and lower GCL. Prior to placement of the thermal cover, a protective layer of HDPE liner was placed over the exposed GCL. Nevertheless, this liner and the GCL were ripped in places by the excavator during the removal of the thermal cover. The GCL was also damaged by the small jack hammer used to loosen the frozen thermal cover. Patches were applied to holes, damaged areas, and areas where insufficient exposed GCL remained for joining the upper and lower GCL. In some areas the damage occurred near the toe of the frozen core material; therefore, a portion of the frozen core material was thawed and removed in order to properly patch the damaged area.

Upper GCL cover placement proceeded from the ends of the dam towards the inflection point and was directly followed by GCL cover material placement. As a result of this construction sequence, bleed water from the GCL cover material ran onto the exposed lower GCL near the upstream core toe. The ice from the bleed water was thawed prior to upper GCL placement.

5.8 GCL Cover Material Placement

As outlined in Section 4.4 the GCL cover material consisted of a 1:1 mixture of 5 mm minus core material and original (20 mm minus) core material. GCL cover material placement was similar to core material placement, however the saturation and freeze-back requirements for this lift were less stringent than the core material specifications. Saturation requirements for the cover material were reduced to prevent excessive bleeding of the cover material on the slope.

Moisture-conditioned cover material was hauled to the dam with CAT 330 haul trucks, and placed with a CAT 330 or CAT 345 excavator. Cover material was placed on the flat areas at the toe and crest of the core; then pushed or pulled upward along the core slope. The material was placed in approximately 0.3 m lifts. Each lift was compacted with the 10 tonne vibratory compactor prior to the placement of the next lift; no freeze-back was required between lifts.

5.9 Transition Material Placement

Transition material was placed with CAT D6 and D8 bulldozers and CAT 345 and 330 excavators. Compaction was provided by a 10 tonne drum vibratory compactor. On the downstream side of the dam, transition material was placed in lifts rising alongside the frozen core material. On the upstream side of the frozen core, the transition material was placed in lifts along the slope. In the extended fillet zone, where the frozen core material was extended, the transition material was also extended such that the design width and thickness was maintained beyond the design lines.

5.10 Placement of ROQ

The ROQ material produced in Quarry #2 was loaded in the quarry with the CAT 385 excavator, the CAT 988, or the CAT 980 loader, and hauled to the dam using the CAT 725 and CAT 730 haul trucks. Placement was done by end dumping and pushing with a CAT D6 or CAT D8 bulldozer. The lift thickness was maintained to a maximum of 1.85 m at all times, and each lift was compacted using the 10 tonne vibratory compactor and by loaded haul trucks using the area as a trafficking surface.

The first areas covered with ROQ were the outer footprint of the dam shell, upstream and downstream of the Key Trench, to create trafficable access for heavy equipment. The snow was removed from the placement footprint, as per the requirements in the Technical Specifications (Appendix C).

When dam construction was suspended in the spring 2011, a 2.5 m thick layer of ROQ was placed as thermal cover. When construction resumed in 2012, ROQ was removed from the core and transition footprint, mixed with the 16 mm (5/8 inch) indicator material, and stockpiled within the footprint of the dam shell. Subsequently, this ROQ was used to build up the shell to the design line. The final surface of the dam shell was graded and shaped using CAT 330, CAT 345, and CAT 325 excavators, and subsequently compacted using the 10 tonne vibratory compactor.

5.11 Instrumentation

5.11.1 General

Instruments were installed to monitor the performance of the North Dam. Some of the instrumentation was installed during construction, while others were installed after completion of the dam. The instrumentation comprises of the following:

- Ground temperature cables,
- Thermosyphon status thermistors,
- Surface and deep settlement monitoring monuments,
- Inclinometers, and
- Automated data acquisition system.

Details of each instrument type are presented in the following sections.

5.11.2 Ground Temperature Cables

A series of ground temperature cables (GTC) were installed in the core and in the foundation of the dam to monitor the temperature of the frozen core and of the permafrost foundation. The cabels location, bead distribution, and cable length are provided in the IFC drawings DN-ND-09 to DN-ND-16 (Appendix A).

Some of the GTCs were damaged during construction by equipment used for clearing snow and placing or moving transition and ROQ material. Cut GTCs were spliced by the contractor when possible. Table 5-3 provides a status summary of each GTC.

Table 5-3 Ground Temperature Cable Status Summary

String #	GTC Designation	Station	Status	Comments
1	ND-VTS-040-KT	0+40	Active	Nicked. Electricians cut and spliced.
12	ND-HTS-040-31.5	0+40	Active	
13	ND-HTS-040-33.5	0+40	Active	
2	ND-VTS-060-US	0+60	Active	Cable of insufficient length to cross crest of dam. Extension added by Nuna electricians.
3	ND-VTS-060-DS	0+60	Active	Spliced after being cut.
4	ND-VTS-060-KT	0+60	Active	Spliced after being cut by equipment during snow removal.
14	ND-HTS-060-28.8	0+60	Active	Spliced after being cut. One bead not working.
15	ND-HTS-060-31.0	0+60	Active	
16	ND-HTS-060-33.5	0+60	Active	
5	ND-VTS-085-US	0+85	Active	
6	ND-VTS-085-DS	0+85	Active	
7	ND-VTS-085-KT	0+85	Active	
17	ND-HTS-085-25.3	0+85	Active	

String #	GTC Designation	Station	Status	Comments
18	ND-HTS-085-29.4	0+85	Active	
19	ND-HTS-085-33.5	0+85	Inactive	Permanently disabled after being cut. Could not find end to splice.
8	ND-VTS-130-US	1+30	Active	
9	ND-VTS-130-DS	1+30	Active	Spliced after being cut.
10	ND-VTS-130-KT	1+30	Active	
20	ND-HTS-130-28.8	1+30	Active	
21	ND-HTS-130-31.0	1+30	Active	
22	ND-HTS-130-33.5	1+30	Active	
11	ND-VTS-175-KT	1+75	Active	Spliced after being cut. Connector termination switched with ND-HTS-175-33.5.
23	ND-HTS-175-32.5	1+75	Active	
24	ND-HTS-175-33.5	1+75	Active	Spliced after being cut. Connector termination switched with ND-HTS-175-KT.

Note: * GTC grouped by transect perpendicular to the dam axis.

5.11.3 Vertical GTC Installation

Installation of the vertical GTCs was performed after the levelling course was placed to an elevation of 30.3 masl in the Key Trench, and the first lift of ROQ was placed to the dam shell footprint. Backfilling the annulus around the cables was done using dry core material or manufactured fines, as opposed to the wet slurry specified in the Technical Specifications (Appendix C). Another deviation from the design is that cables were routed in 1 m deep trenches as opposed to being placed in surface pipes, as shown on IFC drawings DN-ND-14 to DN-ND-16 (Appendix A). The cables were imbedded in a 30 cm layer of dry core material and covered with 30 cm of the same material, before the trench was backfilled with ROQ. Yellow warning tape was laid out on top of the protective core material.

A short portion of cables ND-VTS-060-US and ND-VTS-085-US near the upstream toe of the dam were encased in a steel pipe. The remainder of the cable leads were run up the trench.

Key Trench GTC Installation

Key Trench GTC installation was performed by drilling through the frozen material to the appropriate depth. The design elevation of the top temperature bead was maintained, even though in most instances because of over-excavation of the Key Trench, the top bead was located within frozen core material rather than overburden. The Key Trench GTC lead cables were stretched to the downstream core toe, routed vertically to an elevation of 33.5 masl along the downstream of the core, and bundled up with the overlying horizontal GTC cables. At elevation 33.5 masl the bundles of leads were stretched out to the downstream crest of the dam shell and then routed up the face of the dam in a 1 m deep trench, which terminated at the downstream crest of the dam.

Upstream and Downstream GTC Installation

Upstream and downstream GTCs were installed in a similar manner to the Key Trench GTCs - drilling through the first layer of ROQ placed on the dam shell footprint. The lead cables were stretched out to the toe of the ROQ and coiled up until the dam shell was completed. On the upstream side only, the leads were initially placed into 51 mm (2 inch) steel pipes and routed up the face of the dam to the elevation of the first ROQ lift. Subsequently, these leads were excavated and the pipes were removed where possible, while the cables were re-routed up the dam face in a 1 m deep trench, which crossed the dam centerline and terminated at the downstream crest. This was done to eliminate the fold in the cable at the toe of the dam shell, and to gain some length to allow the cables to cross onto the downstream side without an extension being required.

The downstream cables were routed up the face of the dam in the 1 m deep trench and terminated at the downstream crest.

5.11.4 Horizontal GTC Installation

The horizontal GTCs were installed at the design elevations and positioned by laying out the cables and covering them with core material as construction proceeded. Bentonite water stops were placed between each bead of the GTC. For some strings, the first few beads were temporarily left uncovered due to the construction sequence of the core material. The lead cables were bundled up with the vertical GTC leads and routed vertically along the downstream face of the core to elevation 33.5 masl. From there, all cables were stretched out horizontally to the downstream crest of the dam shell, and then the cables were placed in the 1 m deep trench and bedded in core aggregate, together with the lead of the downstream vertical GTC.

5.11.5 Thermosyphon Status Thermistors

A series of Thermosyphon Status Thermistors (TST) were attached to the riser of each thermosyphon radiator. These single-bead thermistors (CS109, manufactured by Campbell Scientific) allow monitoring of the thermosyphon operation during the active cooling season. Monitoring is done by measuring the temperature of the radiator pipe where it exits the ground (this is equivalent to measuring the temperature of the coolant agent in the thermosyphon) and comparing it to the ambient air temperature. During the active cooling season the coolant agent within the thermosyphon where it exits the ground is expected to be a minimum of $5^{o}C$ warmer than the air temperature.

The TST were attached to the thermosyphon radiators as close to the riser elbow as possible using epoxy resin adhesive, and insulated using spray foam. Photos of the installation are shown in Appendix G.

The lead cables of the TSTs at each radiator cluster were brought together and laid in a shallow trench (about 0.5 m deep) before feeding into a 2 inch diameter steel conduit. The conduit runs between the thermistor cluster and the nearest instrument node and was buried into a shallow trench excavated on the shell of the dam. See As-built drawings DN-ND-13 and DN-ND-27 (Appendix B) for details.

At the north radiator cluster the TST lead cables were connected into Multiplexer #9 in Node E. The leads from the south radiator cluster were routed to Node A and from there fed through the pre-installed metal conduits along the crest of the dam and connected into Multiplexer #9 in Node E (Appendix L.1). Where no metal conduit was pre-installed during dam shell construction (between ND-ISP-085 and ND-ISP-130) a 0.8 m deep trench was excavated along the crest of the dam. The pipe was covered with 0.3 m of 20 mm minus crush and then the trench was backfilled to grade with the excavated ROQ. The final surface was not compacted.

Relative depth of installation of the TST's was measured from the lowest horizontal cross beam of the radiator support structure. The details of the TST's are presented in Table 5.4.

Table 5-4 Location of the Thermosyphon Status Thermistors

Thermosyphon Location	Installation Location (m)*	Thermistor Serial number
TS-31	0.92	1347
TS-32	0.93	1351
TS-33	0.71	1352
TS-34	0.68	1349
TS-35	0.58	1353
TS-36	0.45	1350
TS-1	0.87	1345
TS-2	0.68	1343
TS-3	0.73	1342
TS-4	0.58	1346
TS-5	0.59	1344
TS-6	0.51	1341

Note: *measured down from the bottom of the lower cross brace

5.11.6 Survey Monitoring Points

Three types of survey monitoring points have been installed within the North Dam as follows:

- Fourteen survey monitoring points installed at the crest of the dam on the upstream and downstream sides on top of the frozen core material, to monitor any movement of the frozen core material.
- Eighteen surficial survey monitoring points installed in large ROQ boulders placed in a grid pattern on the downstream face of the dam. These will monitor any deformation of the dam shell.
- Three deep settlement points installed 0.5 m into the original ground below the ROQ shell. These settlement points are located on the downstream side of the dam at stations 0+70, 1+00 and 1+20. These will be used to monitor any movement of the foundation materials of the dam.

Complete details of these installations are described in the following sections.

Crest Survey Monitoring Points

Locations of the crest survey monitoring points, located along the upstream and downstream crest of the North Dam, are shown on as-built drawing DN-ND-08 (Appendix B). The survey monuments were manufactured by the Contractor on-site, according to the specifications detailed on drawing DN-ND-16 (Appendix A).

Installation of the monitoring points was performed after the dam shell was constructed to its final elevation. Placed ROQ and transition material was excavated to the required depth and compacted core material was placed to provide a levelling course. The monitoring point base and rod were installed, and then compacted core material was placed around the rod prior to the installation of the 102 mm (4 inch) housing. The excavation was backfilled with ROQ material placed in 1 m lifts and compacted manually with a plate tamper.

Surficial Survey Points

Upon completion of dam shell construction, surficial survey points were installed in a grid pattern on the downstream face of the dam as shown on as-built drawing DN-ND-30 (Appendix B). A CAT 345 excavator was used to excavate a shallow hole into the ROQ dam shell into which a thin (0.3 m) lift of uncompacted dry core material was placed. A 1 m diameter boulder was placed into the excavation, ROQ material was replaced around the boulder and the dam surface was compacted with a 10 tonne vibratory compactor. A 38 mm (1.5 inch) hole was drilled into the boulder into which an expansion bolt was secured.

Deep Settlement Points

The deep settlement points were also installed after construction of the dam shell was completed. These settlement points are located along the downstream face of the dam approximately 7 m from the downstream crest of the dam, as shown on as-built drawing DN-ND-30 (Appendix B).

The deep settlement point casings were installed to a depth of 0.5 m below the original ground surface; however the 152 mm (6 inch) diameter boreholes were drilled to a depth of 13 m below the dam shell surface. The over-drilled portion of the boreholes was filled with dry core material, and the inner 102 mm (4 inch) outer diameter pipe was installed. The top of the outer steel casing was extended such that the top of the inner pipe was just below the lip of the casing. A protective steel cap was fabricated to cover the outer steel casing; rather than the hinged lid shown in the IFC drawings.

5.11.7 Inclinometers

Six inclinometer casings were installed after construction of the dam shell was completed. Three inclinometers were installed along station 0+70 and three along station 1+20. The inclinometer instruments and casings were ordered from Durham Geo Slope Indicator. The location of the inclinometer installations are shown as-built drawing DN-ND-30 (Appendix B).

Inclinometer casings were installed by drilling a 152 mm (6 inch) diameter hole a minimum of 5 m below the original ground level, 0.5 m beyond design depth. The inclinometer casing was then slid into the hole, and the annulus was backfilled with dry core material. Prior to placement of the inclinometer casing, the over-drilled portion of the borehole was filled with dry core material. A water lance was used to saturate the in-place core material to ensure no bridging. The inclinometer casing was assembled according to the manufacturer’s instructions. A protective casing of 152 mm (6 inch) steel pipe, extending 1.1 m above grade and 1.5 m into the ROQ, was placed over the top section of the inclinometer casing. A steel tab was welded to one side of the protective casing to prevent the casing from sliding into the borehole prior to the backfilled material freezing. A protective cap was manufactured on-site to go over the protective outer pipe.

After inclinometer casing installation was complete, a dummy probe was sent down the casings to check they were functioning properly.

5.11.8 Automated Data Acquisition System

An automated data acquisition system was installed to allow continuous recording of GTC and TST data. System layout details and components are included in Appendix L, as well as on IFC drawings DN-ND-08, DN-ND-16, and DN-ND-32 (Appendix A).

The system consists of a series of nine AM16/32 multiplexers connected to two CR1000 data loggers, all manufactured by Campbell Scientific. The ground temperature cables and the thermosyphon sensors are connected to the multiplexers, which in turn are connected to the data loggers.

The data loggers and the multiplexers are housed inside weatherproof enclosures mounted on each data logger and battery support post. A second enclosure was installed on each support post directly below the instrumentation housing, and was used for cable management purposes. Due to the fact that the thermistor cables were re-routed as described in Section 3.8, considerable excess length of cable remains at some of the ground temperature cable nests. The excess cable lengths which could not be included in the enclosures were coiled and buried at the base of the support post. The coils were bedded into and subsequently covered with a minimum of 0.3 m of 20 mm minus.

Each data logger and its peripheral multiplexers are powered by a 100 Ah 12VDC battery housed in a dedicated enclosure attached to the support post. The batteries do not have self-recharging capability, and will have to be recharged using AC trickle charger. The large capacity is meant to ensure that sufficient power is available to allow operation for an entire year.

The data loggers are taking point measurements from the GTC's and the TST's every 6 hours, at midnight, 6AM, noon, and 6PM. In addition, the battery voltage and the ambient temperature inside the enclosure are recorded each time point measurements are taken.

6 Quality Control and Quality Assurance Testing

6.1 General

Quality Control (QC) and Quality Assurance (QA) testing for the North Dam were done in accordance with the Technical Specifications (Appendix C). Responsible parties included SRK and Nuna. On-site testing was performed by EBA, A Tetra Tech Company (EBA) subcontracted to SRK, using the on-site geotechnical laboratory provided by HBML. The Troxler nuclear densometers used for the project were owned and operated by EBA.

A total of 2,078 laboratory tests were performed during construction of the North Dam. The majority of those were analyzed on-site; however, some of the specialized testing (salinity and specific gravity), and some duplicate particle size distribution (PSD) testing was done off-site at EBA's laboratories in Edmonton and Yellowknife. Appendix H contains the results of all tests performed and the laboratory test certificates. Figures 3 through 29 graphically display test results.

6.2 Overburden

6.2.1 Percolation Testing

The percolation test program was comprised of 23 boreholes and was done in accordance with the methods detailed in the specifications (Appendix C). Warm water was supplied from the camp kitchen. Complete details are provided in Section 5.3.1 and the results are presented in Appendix J.

6.2.2 Salinity Testing

Salinity testing of samples collected from boreholes during the percolation testing program, as well as from dedicated boreholes testing the Soft Spot, were analyzed using the Refractometer method. On-site salinity testing was attempted but was unsuccessful; therefore, the testing was performed at the EBA laboratory in Edmonton. A total of 55 tests were performed, with salinity generally ranging between 30 and 60 parts per thousand (ppt), with extreme results as low as 4 ppt or as high as 90 ppt. Test certificates are contained in Appendix H.8.

As a result of these findings, the high salinity material was subsequently removed as described in Section 5.3.2.

6.3 Core Material

6.3.1 Particle Size Distribution

PSD tests were performed on core material samples taken from the crusher in accordance with the Technical Specifications (Appendix C). In 2011, samples were collected by SRK/EBA or the crusher operator from the finished product stacker belt. In 2012, samples were collected by the crusher operator using a loader bucket placed under the discharge of the stacker belt.

The PSD envelope for core material outlined in the Technical Specifications proved to be ineffective as described in Sections 3.3 and 4.3.1. A revised PSD envelope was subsequently adopted as specified in Figure 2. The results of all the tests carried out are summarized in Figure 2, and the laboratory test certificates are listed in Appendix H.1.

In some cases, the samples did not satisfy the revised gradation requirements, mainly due to low fines content. No action was taken to correct the gradation based on these failed results, given that the bulk of the material did satisfy the requirements, and a thorough blending of the specific batches with the rest of the material occurred during handling and water conditioning in the FCP.

Samples from the Frozen Core Plant

PSD testing on samples from the FCP are summarized in Figure 2, and the test certificates are included in Appendix H.1. The samples were collected from the chute of the mixing drum in the FCP.

Samples from Frozen Cores

Once the drilled core samples were processed for density and moisture content, the dry residual core material of several drilled core samples were blended and one PSD test was performed for each complete lift, as specified in the Technical Specifications (Appendix C). The results are shown in Figure 2, and the test certificates are contained in Appendix H.1.

6.3.2 Moisture Content

Moisture content of core material was determined using the Troxler gauge, or in the laboratory from samples collected from the chute of the FCP, or as part of ice saturation and PSD tests. Test results can be seen in Appendix H.3 and H.4.

A comparison between the moisture content values measured by the Troxler gauge and the actual moisture content determined in the lab, showed a significant (about 2% on average) and inconsistent (random) error. Therefore, during the latter part of the 2012 construction season, laboratory moisture content determination of samples collected from each density test location was used to estimate the wet (unfrozen) saturation of the placed core material.

A total of 802 tests were performed in the field laboratory, for a minimum testing density of one sample per 50 m^3 of placed core material. Figures 27 and 28 show the test results, compared to the optimum moisture content of the specific material. In cases where the field moisture content (as determined by the Troxler densometer and confirmed by laboratory testing) was below specifications, the core material was removed before freeze-back.

6.3.3 Compaction

Standard Proctor Density Tests

Table 6-1 presents a summary of the Standard Proctor tests used for in-situ density testing. Although Specific Gravity is not part of the Standard Proctor testing procedure, it was included in the summary table as it is used in the field to calculate the degree of saturation of the moisture-conditioned core material at placement, and to define the zero air voids curve. Test certificates are included in Appendix H.2.

Table 6-1 Standard Proctor Test Results used for In-Situ Density Testing

Material ID	Material Description	Standard Proctor ID	Maximum Dry Density (kg/m^3)	Optimum Moisture Content (%)	Specific Gravity
M1	3:2 FCM	-	2275	9.0	2.890
M2	F	-	2145	9.5	2.882
M3	1:2 FCM	-	2255	8.4	2.888
M4	1:1 FCM	-	2290	8.0	2.906
M5	3:2 FCM	HB12-FCP-CORE-SP1-QA-20120431	2280	8.0	2.890
M6	Recrushed 3:2 FCM	HB12-CR-CORE-SP2-QA-20120210	2210	9.4	2.890
M7	5 mm Minus FCM	HB12-CR-SP3-QA-20120216	2160	10.1	2.901
M8	5 mm Minus FCM	HB12-CR-CORE-SP5-QA-20120228	2205	8.5	2.901
M9	5 mm Minus FCM	HB12-FCP-CORE-SP6-QA-20120305	2230	8.7	2.901
M10	5 mm Minus FCM	HB12-ND-CORE-SP8-QA-20120318	2200	8.8	2.901
M11	GCL Cover Blend	HB12-FCP-COVER-SP10-QA-20120324	2250	9.5	2.901

In the case of the M1 material a total of seven Proctor tests were performed, but only the value tabulated above was actually used as input for further testing. Test certificates of all tests are included in Appendix H.2.

Field Compaction Testing

Field compaction was measured using a Troxler nuclear densometer. A total of 822 compaction test results were recorded for a minimum required testing frequency of one test per 225 m^2 covered area per lift (Appendix C). In some instances the number of actual density tests performed was higher than the number of recorded tests, specifically where visual inspection by the SRK field engineer revealed non-homogeneous core material or where difficult placement conditions were encountered. In addition to determinations of the dry density and relative compaction, the Troxler densometer also measured the moisture content at the test location and calculated saturation. Figures 4 to 11 present the field compaction results relative to the referenced Proctor density used for that specific material.

In four instances, where test results indicated densities below the minimum required, compaction efforts were intensified by increasing the number of passes with the compactor. No material was removed based on compaction testing results only, provided that saturation (the primary pass/fail criterion) was achieved.

6.3.4 Ice Saturation

Ice saturation was determined to be the ultimate acceptance criterion for the placed frozen core material. Saturation testing was performed on core samples taken from a previously placed, completely frozen (below -2°C) lift, using a concrete coring machine. The core samples were typically 15 to 20 cm long and 10 cm in diameter. The samples were processed in the field laboratory; several parameters were calculated, ice saturation being one of them.

A total of 134 successful tests were performed and an additional 14 samples collected, but the tests of these 14 samples failed to meet the testing standards and were discarded. One tested sample failed the absolute minimum saturation criterion of 80%, while the average minimum saturation of 85% was achieved in all but 19 samples. The frozen core material exhibiting substandard saturation of 78.5% was left in place, as it was limited to one specific lift located downstream of the core centerline.

Figures 20 to 26 present the test results compared to the specified limits (Appendix C), while Appendix H.5 is a complete compilation of the test certificates.

6.3.5 Bulk Density and Air Saturation

Determination of bulk density was performed in the field laboratory on frozen core samples collected from the chute of the FCP. The test results are attached in Appendix H.6.

6.3.6 Specific Gravity

Specific gravity determinations were performed in the EBA laboratories in Yellowknife and Edmonton, on samples collected from the crusher. The complete test certificates are compiled in Appendix H.7.

6.4 Transition Material

Two transition material PSD curves were completed; Figure 3 presents a summary of the curves. Both samples were collected from the crusher stockpile. One sample was shipped to EBA's laboratory in Yellowknife for testing, while the second was tested on site. The test certificates are presented in Appendix H.1.

6.5 ROQ

In accordance with the specifications (Appendix C), visual inspection of the run-of-quarry (ROQ) material was performed by SRK, both at the loading point in Quarry #2, and during placement on the dam. Oversize or deleterious materials were identified and removed.

6.6 GCL Liner

Visual inspection of the geosynthetic clay liner (GCL) was performed prior to deployment, as well as during installation. The liner rolls were inspected visually by the SRK site engineer to determine suitability (i.e., general state, signs of hydration, and obvious defects) prior to placement. The manufacturer's quality certificates are compiled in Appendix K. During placement each panel was carefully inspected, and, where defects or damage was noted, patches were installed, or the liner was rejected. The seams between the successive panels were also inspected to ensure a minimum of 0.4 kg/m of bentonite powder was applied.

7 Long Term Monitoring

7.1 Context

The North Dam has been designed as a water retaining structure and its successful performance is dependent on maintaining the integrity of the frozen core through preservation of permafrost in the dam foundation. As a result of the high salinity and variable ice content of the foundation soils, creep deformation is expected over the life of the structure, which coupled with the variable foundation soil type, will manifest in differential settlement longitudinally and transversely across the dam. In order to track whether deformations are within the design limits for the dam, a rigorous monitoring program has been established.

7.2 Approach

Responsibility for undertaking the monitoring program as presented here rests with HBML. It is however recommended that the monitoring be carried out under the guidance of either the Engineer-of-Record for the North Dam, or alternately an independent qualified licensed Geotechnical Engineer.

As a minimum, the qualified individual should conduct an annual physical inspection of the dam under snow and ice free conditions (i.e. summer season), consistent with the Canadian Dam Association guidelines for surveillance of dams (CDA 2007). As part of this inspection the inspector should review and analyze all monitoring data to assess whether the dam is performing in accordance with its design criteria. This inspection should culminate with the delivery of a formal Inspection Report that documents the inspection findings, including recommendations pertaining to remediation measures for the dam, its instrumentation, operation, and monitoring requirements. It is therefore expected that the monitoring requirements as specified in this report will be dynamic and may change over time.

In accordance with the Type “A” Nunavut Water Board (NWB) License 2AM-DOH0713, dated September 19, 2007 under which the North Dam has been approved for construction and operation, HBML is obligated under Part J, Items 18 and 19, to ensure that an Annual Geotechnical Inspection be carried out by a Geotechnical Engineer. This inspection needs to be carried out in accordance with the Canadian Dam Safety Guidelines (CDA 2007), and should include all major earthworks, including the North Dam. The inspection is to be carried out between July and September annually, and a report documenting the findings of this inspection must be submitted to the NWB within 60 days. It is anticipated that the North Dam inspection stipulated above, and the annual License Compliance Inspection will be one and the same.

7.3 Monitoring Elements

7.3.1 Thermal Monitoring

Ground Temperature Cables

The frozen core and the underlying foundation have been designed to remain frozen for the life of the structure. The core should at all times be a temperature of at least -2°C, while the underlying foundation soils must be a temperature of at least -8°C (SRK 2007). Thirteen horizontal ground temperature cables have been installed to monitor the core temperature, and 11 vertical ground temperature cables have been installed to monitor the foundation temperature (DN-ND-14 to DN-ND-16 in Appendix B). One of the horizontal ground temperature cables (ND-HTS-085-33.5) was damaged beyond repair during construction and a replacement could not be installed.

All ground temperature cables are connected to a single automated data logger (see Appendix L for complete details) which allows data collection at any frequency. As a minimum, during the initial year following construction, the collection frequency should be set to weekly.

Thermosyphon Monitoring

Horizontal sloped passive thermosyphons installed in the base of the Key Trench are designed to promote freezing conditions in the foundation soils. The thermosyphons are sealed pressure vessels and do not have moving parts that require service or maintenance. A thorough physical inspection for signs of corrosion is required, as well as an annual check on whether they are functioning as designed. The Standard Operating Procedure (SOP) for monitoring the thermosyphon performance is presented in Appendix I, and should be carried out annually when the ambient air temperature is consistently below -20°C.

7.3.2 Deformation Monitoring

Survey Monitoring

The North Dam is expected to undergo significant deformation as a result of creep over its design life, which includes differential longitudinal and transverse settlement. These settlements are expected to result in strains of less than 2% in the frozen core of the dam (SRK 2007). A total of 35 survey monitoring points were installed within the dam to track these deformations such that it can be confirmed that they are within the specified design limits.

The installed monitoring points are illustrated in ND-DN-30, in Appendix B, and include the following:

- Three deep settlement points, located on the downstream slope of the dam, intended to track deformation of the foundation soils in close proximity of the shell;
- 18 surficial survey points, located on the downstream shell of the dam, intended to track deformation of foundation soils at the location of maximum expected deformation; and
- 14 crest monitoring points, located along the crest of the dam, intended to monitor differential settlement, as well as deformation of the upper part of the core.

For the first year following completion of construction, these points must be manually surveyed at least once a month to an accuracy of ±2 mm (horizontal and vertical).

Inclinometer Monitoring

Six inclinometers were installed on the downstream slope of the dam, along the zone of the dam expected to undergo the maximum amount of deformation, and thus subject to the maximum strain. For the first year following construction these instruments must be monitored manually on a monthly basis.

7.3.3 Water Balance Monitoring

An analysis of the thermal performance of the dam can only be properly done in conjunction with an accurate determination of the water level behind the dam, and measurement of any seepage emanating from the dam. Monitoring of the water level can be done by monthly survey measurements of the water level in conjunction with the survey monitoring points, or alternately through installation of a calibrated “LevelLogger”.

Dam seepage is not expected. However, if seepage is noted it must be monitored, including making an estimate of the flow and collection of a water sample for testing to confirm its origin.

7.3.4 Visual Monitoring

A daily visual inspection must be carried out of the dam and all its components looking for obvious signs of distress. A comprehensive visual inspection must be carried out as part of the Annual Geotechnical Inspection.

7.4 Summary of Monitoring Requirements

A summary of the monitoring requirements and associated responsibility is listed in Table 7-1. These monitoring requirements can be revised at any time under the direction of the North Dam Engineer-of-Record, or the qualified Licensed Geotechnical Engineer carrying out the annual inspection.

Table 7-1 Summary of Monitoring Requirements

Element	Item	Method	Responsibility	Frequency
Thermal	Ground Temperature Cables	Data Loggers	Newmont	Daily
	Thermosyphons	Manual	Newmont	Annually
Deformation	Crest Settlement	Manual	Newmont	Monthly
	Downstream Surface Settlement	Manual	Newmont	Monthly
	Downstream Deep Settlement	Manual	Newmont	Monthly
	Inclinometers	Manual	Newmont	Monthly
Water Balance	Water Level	Data Logger	Newmont	Daily
	Seepage Rate	Manual	Newmont	As Required
Visual	Walkover Survey	Manual	Newmont	Daily
	Annual Geotechnical Inspection	Manual	Independent Qualified Licensed Geotechnical Engineer	Annually

8 Final Remarks

The report *"Hope Bay Project, North Dam As-Built Report"* was prepared by SRK Consulting (Canada) Inc.

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Disclaimer

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